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DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS

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EXPANSION AND CONTRACTION
OF
ASPHALT CONCRETE MIXES

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SYNOPSIS

For some time the Materials and Research Department of
the California Division of Highways has been conducting a
research study on the expansion and contraction of asphalt
concrete mixes. These mixes were fabricated using aggregates
ranging from nonabsorptive to highly absorptive.

Data indicates that the AC test specimens fabricated
from absorptive aggregates and exposed to normal atmospheric
conditions absorb moisture from the air which may cause con-
siderable expansion. During the warmest hours of the day,
these expanded specimen contract, causing transverse or so-
called block cracking. Identical specimens kept in a dry
storage cabinet did not exhibit this phenomenon. Absorptive
test bar specimens have shown as much as 2% increase in
length after being subjected to wet and dry cycles for
approximately two months. AC briquettes fabricated from
highly absorptive aggregate and exposed to normal climatic
conditions have shown as much as 18.8% increase in volume
after six years exposure. The type of cracking found in
pavements appears to be the same as observed in laboratory

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specimens when both are fabricated from the same highly
absorptive aggregates.

Strains created in a pavement by this cycle of expansion
and contraction, together with deflections imposed by loads,
may lead to a serious reduction in service life.

This study presents data showing expansion can be re-
duced by certain mineral fillers, while other fillers in-
crease expansion. Expansion can also be greatly reduced by
increasing the asphalt content of the mix consistent with
other specification requirements of the mix.

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INTRODUCTION

In certain areas of California, aggregates of varying
degrees of absorption are the only economical sources of
road building material available. Although these aggre-
gates appear to present no great problem when used in the
construction of bases and subbases, some evidence of dis-
tress is noted when these aggregates are used in the con-
struction of asphalt concrete surfacing. A considerable
mileage of pavement has been placed using these aggregates.

It can be generally stated that the California Division
of Highways has had more failures and distress in asphalt
concrete pavements containing absorptive aggregates as com-
pared with pavements using nonabsorptive aggregates. Two
main types of distress have been encountered which appear
to be related to the degree of absorption of the aggregate.
The first is "drying out" and ravelling of the mix. This
can be caused by rapid oxidation of the binder, insufficient
asphalt in the mix, or the ability of the aggregates to con-
tinue absorbing the asphaltic binder. The second is the
appearance, in a few years, of excessive shrinkage cracks.

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On one of our roads these shrinkage cracks, about 1" wide, were at right angles to the center line and at intervals of about 15 to 30 feet. The aggregates used were highly absorptive as determined by our new test method which is described later. There was no evidence that this cracking was caused by reflection from the base. It has been noted that similar cracks often appear in short sections of AC pavement which are closed to traffic pending extension by future construction.

The most widely accepted theories of asphalt concrete pavement failures are:

    (1)   Pavement fatigue[1,2,3,4,5,6]

    (2)   Excessive deflections[1,6]

    (3)   Radius of curvature of deflected pavement[7]

    (4)   Rapid hardening of the asphalt binder[8]

In addition to the before-mentioned causes of failure, it is apparent that at least one more factor should be included and that is the expansion-contraction cycle of asphalt concrete mixes utilizing absorptive aggregates.

One prime difficulty in the use of absorptive aggregates is the determination of the optimum asphalt content and initially introducing sufficient asphalt to prevent drying out of the pavement and still provide sufficient stability to prevent rutting or shoving of the mix at the time of construction. About 20 years ago we developed the

Centrifuge Kerosene Equivalent Test[*] (CKE) which provides an optimum asphalt content based on a combination of two factors; namely, surface area and absorption. This test has given excellent service and our Standard Specifications contain certain limiting factors (K Factors) obtained from the CKE Test in order to eliminate or reduce the number of highly absorptive aggregates used. The CKE Test is now in the process of modification in order to provide separate quantitative measures of the surface area and absorptiveness of the aggregate. Therefore, in future specifications this determination will permit us to limit the absorption factor. A tentative limit of 0.5% absorption has been adopted for future specifications. A brief description of the modified CKE Test will be presented in this paper.

The excessive shrinkage cracking in pavements containing absorptive aggregates has been of concern to the Materials and Research Department for a number of years. Laboratory studies indicate that the most likely cause of this form of distress is absorption of moisture from the air through the asphalt film which causes considerable expansion of the pavement. When subjected to drying, contraction and cracking appear. Studies with nonabsorptive aggregates did not exhibit this phenomenon. There is little doubt that strains created in the pave-

[*] Use of the Centrifuge Kerosene Equivalent as applied to determine the required oil content for dense graded bituminous mixes, by F. N. Hveem, A.P.P.T. 1942.

ment by this cycle of expansion and contraction, together with deflections imposed by loads, lead to a serious reduction in service life of the pavement.

The purpose of this report is to present the development of laboratory tests for studying the expansion and contraction of asphalt concrete mixtures using absorptive aggregates during cycling under moist and drying conditions and the tentative correlation with pavement performance. A method for measuring the degree of absorption of the aggregate and expansion of the mixture will be outlined.

Also, methods for reducing the degree of expansion will be presented, together with future studies on the probable causes of these findings.

Laboratory Studies

Our laboratory studies are grouped under three parts:

    Part I   Early studies on compacted AC briquettes.

    Part II   Study on compacted AC slab.

    Part III Present studies on compacted AC bars.

Part I: Early studies on compacted AC briquettes.

In 1958 a series of AC briquettes, 3" high and 4" in diameter, were fabricated from highly absorptive and also nonabsorptive aggregates. These briquettes were compacted by our Kneading Compactor and were made primarily for visual observation. Half of the specimens were compacted at 500 psi

and the remaining samples were compacted at 350 psi. The
laboratory test results for these briquettes are shown in
Table 1.

Previous data indicated that specimens compacted at
350 pounds per square inch are about equal in density and
stability to a newly compacted AC pavement, whereas a
compaction pressure of 500 pounds per square inch, as
used in our standard laboratory procedure, produces a
specimen which is about equal to the density of a pave-
ment after a period of time under traffic.

Some of the AC briquettes made from absorptive and
nonabsorptive aggregates were capsulated with epoxy resin.
By coating the briquettes we felt that oxidation of the
asphalt binder would be negligible. Therefore, any change
in the hardness of the asphalt would be caused by the
aggregates. Briquettes, both capsulated and noncapsulated,
were divided into identical groups and weathered under the
following conditions:

Group 1 = Placed on roof of laboratory exposed
            to normal climate.

Group 2 = Inserted into previously cored holes
            of an existing AC pavement.

Group 3 = Placed in darkened cabinet.

1. Briquettes on Roof. (Group 1)

During a periodic inspection of the briquettes on the
roof shortly after exposure, the specimens made from

highly absorptive aggregates and compacted at 500 psi were
showing signs of expanding. Hairline cracking and stretch
marks were visible in the epoxy coating. About three
months from the time the specimens were placed on the roof,
the first signs of cracking appeared in the epoxy coating.
The other briquettes, nonabsorptive and uncoated, under
the same environment showed no signs of stress. This
also includes the highly absorptive specimens compacted
at 350 psi. However, at the end of six months, signs of
distress were visible in the coating of the absorptive
specimens compacted at 350 psi. (Figure 1) We believe
the reason the highly absorptive specimens compacted at
500 psi ruptured their epoxy coating, before the identi-
cal AC samples compacted at 350 psi, is primarily due to
insufficient void space. The samples compacted at 350
psi, obviously possessed a greater percentage of air
voids than the briquettes compacted at 500 psi. This
additional void space permitted the absorptive aggre-
gates to expand without bursting their epoxy coating.
However, when the aggregate's volume increase became
greater than the available voids in the compacted bri-
quette, the specimens compacted at a lower pressure also
ruptured.

  At the end of one year, the highly absorptive speci-
mens compacted at 350 and 500 psi had completely ruptured
their epoxy coating. (Figure 2) However, for the same

period of time, the nonabsorptive capsulated specimens remained in excellent condition. (Figure 3)

The specimens that were not capsulated showed the same trend. The absorptive briquettes had cracks over the entire surface, while the nonabsorptive briquettes showed no signs of cracking. Figure 4 shows their appearance after 6 months. After 6 years the diameter of the absorptive (1.0%) specimen increased from 4.0 inches to an average of 4.25 inches. The height increased from 3.0 inches to 3.15 inches. This is an increase of 18.8% in volume. No expansion in volume occurred in the nonabsorptive briquette. (Figure 5)

After noticing this volume change in the absorptive AC specimen, we made our first attempt to measure the amount of expansion. To the vertical sides of the test specimen made from absorptive and nonabsorptive mixes, ½" long stainless steel reference pins were cemented with epoxy resin. (Figure 6) The specimens were then placed on the roof and expansion measurements were made. However, after about one week, the weight of the pins and the ambient temperature caused the mix around the pins to soften and disintegrate. As will be mentioned later, this problem was overcome by measuring the volume change of a slab and test beam specimen.

2. Briquettes inserted in pavement. (Group 2)

This group of briquettes was inserted into previously cored holes in an existing AC pavement. Some of the bri-

quettes were placed between the wheel track, while the re-
maining briquettes were placed in the wheel track.

The briquettes were placed between and in the wheel
tracks to determine what visible effects the different
wheel loads might have on the test specimens.

The tightly confined briquettes, both in and between
the wheel tracks, showed hairline cracking on the surface
of the absorptive types. However, no signs of cracking
were noted on the nonabsorptive briquettes.

The evidence of surface cracking on the absorptive
specimens indicates expansion and subsequent shrinkage
had occurred, and apparently the force of expansion was
sufficient to slightly move the surrounding pavement.

3. Briquettes stores in darkened cabinet. (Group 3)

Both absorptive and nonabsorptive briquettes which
were stored in a cabinet free from sunlight and moisture
remained in excellent condition. Figure 7 shows the
appearance of these specimens after 6 years. For com-
parison, identical specimens stored on the roof for 6
years (Figure 5) are shown.

We had intended to recover the asphalt from the
Group 1 briquettes and determine if the absorptive aggre-
gates harden the asphalt more rapidly. However, due to
the ruptured epoxy coating, we were not able to complete
this phase.

The excessive expansion of the absorptive samples, and the slight or no expansion of the nonabsorptive samples weathered on the roof and in the pavement, led to the following questions:

1. Why did the absorptive AC samples expand so rapidly?

2. Why did not the nonabsorptive samples expand?

3. What is the maximum expansion that can be expected from absorptive AC mixes?

In answer to the first question, we might state that there probably were microscopic holes in the epoxy coating and asphalt binder. These small openings allowed the moisture to pass through the epoxy and asphalt protective coatings. The absorption of moisture by the aggregates caused a sufficient increase in volume to crack the epoxy coating.

This destructive cycle of moisture absorption and expansion continued until the AC briquettes were completely ruptured. (Figure 2)

The absorptive briquettes which were not capsulated, (Figure 4), had noticeable cracks over their entire surface. Their movements were not confined, allowing expansion and contraction to occur without complete rupture, which was not the case with the capsulated briquettes.

In answer to the second question, we feel that the non-absorptive briquettes, both capsulated and noncapsulated, showing no visible signs of stress indicated no increase in

volume had occurred. We believe the moisture that did enter the briquettes was adsorbed and retained in the void spaces. The hard nonabsorptive aggregates did not absorb moisture; therefore, no over-all expansion was noticed.

In answer to the third question, we may state that the maximum longitudinal expansion recorded to date on one of our test specimens (as described later) was about 0.2 inch.

Part II: Study on compacted AC slab specimen.

In order to obtain better measurements, we decided to fabricate a test slab 1' x 2' x 3" thick. A sample of absorptive aggregate (Table 1) was obtained and mixed with 6.3% of 85/100 penetration paving asphalt. The aggregates and asphalt were mixed under controlled conditions in a Hobart Mixer. This procedure for mixing had been calibrated previously for studies on asphalt hardening against field pugmill mixing. The slab was fabricated in two layers and a syntron hammer used for compaction. The specimen required about 65 lbs. of aggregate and was compacted to a density of 126 lbs/cu.ft.

The test slab was compacted in a heavy wooden split frame and, after compaction, the top portion was removed and replaced with aluminum sides which permitted free expansion and contraction. The unrestrained movement was recorded by six dial indicators, reading to the nearest 0.001", and located around the surface course, see Figure 8.

In June 1961, the above-fabricated slab was exposed to the outside atmosphere. Dial measurements were made every two hours during the working day, and the air and surface temperatures were also recorded five times daily.

Figure 9 represents the expansion and contraction that occurred in a one-week period during the study, which lasted about three months. Figure 10 shows the expansion that occurred during the entire length of test. The cyclic pattern illustrates that maximum expansion for this AC mix occurs during the early morning hours when a considerable amount of moisture is in the atmosphere, while maximum contraction occurs during the warmest hours of the day. It is interesting to note that the test specimen failed to return to its original dimensions during the contraction period. Failure to return to its original size is probably due to structural breakdown of individual aggregates exposed to moisture during the wet cycle. The maximum expansion in width of 0.142" occurred on a day following a rainstorm. The excessive expansion was recorded in September about 3 months after starting date of test. The expansion of 0.142" would have been considerably higher if the lower wooden form had not broken due to the tremendous forces created by the expanding asphalt concrete.

The total expansion in length and width, as recorded, shows an increase in volume of 1.4%. However, we are certain the actual volume increase would have been much

higher if the box had not broken and if we had arranged to determine the increase in thickness of the test specimen.

The above method for fabricating AC mixes to determine the amount of expansion and contraction was discontinued for the following reasons:

1. The amount of material needed to fabricate one sample was approximately 65 pounds.

2. The cost of the box, and the price of six dial indicators for each specimen tested, was considered too expensive.

3. The time required for preparing one sample was excessive.

Part III: Measurement of AC bars.

To reduce the expense of fabricating large test samples, as described above, a new method was adopted. Asphalt mixes were compacted into 3" x 3" x 11.25" steel molds, see Figure 11.

Briefly, the method consists of heating the AC mixture to 230°F, rodding it into 2 layers in the preheated mold, and compacting it with our kneading compactor. Upon cooling, the mold is stripped and the steel pins at the end of the specimen are fastened into place with epoxy. The bar is then placed in a 100°F oven for 3 days for curing. It is then subjected to the weathering cycles, one cycle consisting of 7 days in a moist room and 7 days in a 100°F oven. Daily measurements are made and any cracks or unusual

behavior of the specimen is recorded. The specimen is sub-
jected to a total of 3 to 6 weathering cycles. For detailed
procedure, see Appendix A.

Following this new procedure, test bars were made from
AC samples obtained from current construction projects
throughout the state. Bars were also fabricated from pro-
posed aggregate sources showing varying absorptive
characteristics. (0.0 to 2.8%)

Figure 12 represents results from the first AC bars
tested. These bars were fabricated from highly absorptive
aggregates from two different sources. The results from
laboratory tests on the two sources used for test bars in
Figure 12 are listed in Table 2.

Cracks appeared in Sample #62-1863 during the drying
period of the first cycle. During the third cycle the
sample had expanded over 0.2" with block cracking through-
out the entire sample.   This expansion of more than 0.2"
in a 11.25" bar (1.8% expansion) is the maximum longi-
tudinal increase recorded to date for AC bars.

This exceptionally high expansion was reached after
64 days (Figure 12) exposed to wet and dry periods.

Transverse cracks were visible on Sample #62-1908 at
the end of first cycle. (Figure 13) Rapid expansion
(0.045") at the beginning of the drying cycle suggests
this specimen is susceptible to moisture in the vapor state.
This sample also exhibited several transverse cracks at the

end of the third cycle.

Results show Sample #62-1908 required 13 days in 100°F oven before contraction remained constant. This unusually long period was probably due to the sample's susceptibility to moisture vapor. Sample #62-1863 stopped contracting at the end of six days.

Data shows that the average time required for maximum expansion and contraction is approximately seven days for each wet and dry cycle.

AC pavements constructed with aggregates from the same source as Sample #62-1863 have shown considerable distress in the form of cracking. This aggregate source has now been eliminated for constructing AC pavements, even though this material generally passes all routine physical tests.

Figure 14 is a close-up of Test Bar #62-1863. Transverse cracks appeared first on the surface of the specimen, then progressed downward. At the end of the third cycle the bar was completely block-cracked.

Investigation of Pavement Failure

In 1962 we were asked to investigate an AC pavement failure in one of our districts. This failure (Figure 15) consists of transverse cracks from 3/4" to 1½" wide in the surfacing at irregular intervals ranging from 10 to 20 feet apart throughout the entire project. The pavement was constructed from aggregates obtained from a local pit.

Samples were taken from the existing pavement and also from the aggregate source used in the construction of this pavement. Sufficient material was obtained to complete routine tests as well as expansion and contraction tests. Test results are shown in Table 3.

Differential Thermal Analysis (D.T.A.) Test on the raw aggregate indicated that the minus 200 mesh material contained Nontronite (Iron rich Montmorillonite) and the X-Ray Diffraction Analyzer showed Montmorillonite and layered silicates.

To duplicate the field mix design, laboratory specimen were mixed in the Hobart mixer using 6.3% of 85/100 paving asphalt. After mixing, the samples were compacted (see Appendix A) into test bars and placed in the 100°F oven. After the specified period, the bars were placed in the moist room for the beginning of the test.

Also a test bar 3" x 3" x 11.25" was sawed from a slab sample removed from the existing pavement. The sawed bar was dried in a 100°F oven to constant weight and then placed in the moist room for the beginning of the test.

The expansion and contraction occurring in the laboratory-fabricated specimen and the AC sample bar sawed from existing pavement are shown in Figure 16. Both AC bars show approximately the same rapid expansion in the first few hours of the dry cycle. However, the laboratory-prepared bar expanded more than the bar removed from the

2.   By wasting the minus 200 material, the natural
     barrier for keeping the moisture away from the
     larger absorptive aggregates is removed. Removal
     of this natural water barrier offers the larger
     aggregates a constant supply of available water
     during the wet cycle. When the "dustless"
     (minus 200 material) mix test bar was placed in
     the 100^OF oven, the absorbed moisture entrapped
     in the larger aggregates attempted to escape im-
     mediately by evaporation. However, all the
     moisture could not escape at once through the
     minute interstices, resulting in vapor pressure
     rapidly building up during the first few hours
     of the dry cycle, causing a sharp increase in
     expansion.

Influence of Mineral Filler on Expansion

In July 1961 an experimental test section was con-
structed for the purpose of comparing the effectiveness of
various fillers on an asphalt concrete mix. The control
section was a normal AC mix conforming to our Standard
Specifications without the addition of any commercial
filler. The results of the tests on the AC control sample
as well as the test results on the AC sample with various
fillers are shown in Table 4.

We also decided to fabricate test bars from the various
mixtures to see whether or not expansion would occur.

The mineral fillers and percentage used were:

1. Filler A   2%

2. Filler B   2%

3. Filler C   2%

During road construction, AC samples were taken from the paver from each section including the control section, and test bars fabricated.

Figure 18 represents the expansion and contraction behavior of the test bars.

Following are the results from the AC test bars, as well as the condition survey of the pavement test section:

Filler A

As shown in Figure 18, Filler A expanded excessively during the first hours of the dry cycle. This phenomenon did not occur in the AC control bar or the other AC bars with different fillers added. From results obtained, we assumed that Filler A was the contributing factor which caused this high expansion during the dry cycle. Transverse cracks appeared during the dry period of the first cycle. After cracking, the amount of expansion decreased. This usually occurs when the cracks have progressed through the test bar.

Since July 1961, five condition surveys have been made of this test section. Nine months after completion date, transverse cracks from 1/16" to 1/8" in width were visible at about 10' intervals throughout this section. The amount

of cracking, both transverse and longitudinal, have continued to increase with time. As shown in Table 4, 132 lineal footage of cracking per station was visible during the October 1963 survey.

This filler was also used in an experimental AC test section in another part of the state. This test section also showed cracks appearing shortly after the pavement was completed. It might be added that the aggregates, asphalt, and location were entirely different for these two projects.

Filler B

This mineral filler reduced the maximum expansion from 0.057" to 0.029", or 51%, in comparison with the control bar. No cracks were visible on the test bar after four complete cycles.

The April 1962 condition survey showed slight pitting and a few hairline transverse cracks. However, the last survey made (October 1963) showed no additional cracks or pitting has occurred since the April 1962 survey.

Filler C

This filler did suppress expansion during the first cycle. However, the succeeding cycles showed this additive ineffective in decreasing expansion. Cracking appeared during the drying period of the second cycle.

The pavement survey showed excessive pitting had occurred after December 1961 survey, but prior to the April 1962 survey. Transverse cracks were visible during

the April 1962 survey, and longitudinal cracks were noticed in October 1963 survey.

To summarize the condition of this test section, we feel that Filler B is superior to the control and Filler C section, and that all test sections are superior to Filler A section.

Influence of Asphalt Content on Expansion

It is the policy of the California Division of Highways to recommend the highest possible asphalt content for asphalt concrete mixes, consistent with other specification requirements such as stability. This is particularly important when using absorptive aggregates. Figure 19, representing a fairly absorptive aggregate, shows that the maximum expansion has been decreased from 0.049" to 0.008" by increasing the average asphalt film thickness by one micron. The same increase in film thickness of a nonabsorptive or slightly absorptive aggregate will only reduce the expansion slightly, as illustrated in Figure 20.

Modified CKE Test

Modification of the Centrifuge Kerosene Equivalent Test (CKE) made it possible to show the relationship between expansion and contraction and the absorption of the aggregates used in fabricating test bars. Our present CKE Test is based on factors, which include both surface area and absorption. Certain limits (K Factors) are provided in our Standard Specifications in order to eliminate or reduce the

existing pavement during the wet cycle. The reason why the
laboratory AC bar expanded more during the wet cycle is pro-
bably due to the fact that the asphalt in the specimen from
the existing pavement had a longer time to be absorbed by
the absorptive aggregates (both fine and coarse). This
added depth of penetration of asphalt into the aggregates
partially sealed off the pores of the aggregates and pre-
vented it from absorbing water, therefore expansion would
would be reduced during the wet cycle.

We also felt that the expansion could be related to
the type of clay (nontronite) that was present in the mix.
In order to see what effect the nontronite clay had on
the expansion of the test bars, a specimen with the clayey
portion removed was fabricated. The results shown in
Figure 17 indicate that expansion was considerably re-
duced in the wet cycle. However, in the dry cycle, ex-
pansion was greater and somewhat more abrupt than in the
regular test bar.

We believe that explanations for less expansion
during the wet cycle and greater expansion in the dry cycle
are:

1. The minus 200 material contained a considerable
amount of clay (nontronite). When this expansive
clay was removed from the AC mix, the total amount
of expansion during the wet cycle was also
reduced.

number of highly absorptive aggregates used. This test has
been used by the California Division of Highways since 1940
to indicate the amount of oil or asphalt required for a
given mix and has given excellent service. The modified
CKE Test treats surface area and absorption of the aggregate
as two distinct and separate factors. This test has been in
use by us for several years, primarily as a research tool.
However, it has not officially replaced our present CKE
Test (California Test Method No. 303-D).

We are presently in the process of setting limiting
values for absorption, and the modified CKE Test will be
the subject of a separate paper.

The equipment for the modified CKE Test is identical
to the one used for our present test. Briefly, the pro-
cedure consists of placing 100 grams of the combined aggre-
gate (up to 3/4" maximum) in the centrifuge cup, pouring
20 ml. of kerosene over the sample, and centrifuging it
immediately (within 5 sec.) for a period of 2 minutes at
400 times gravity. The sample is then weighed and the
surface area is determined from the amount of kerosene re-
tained. The same sample is then placed in a small pan of
kerosene and is permitted to soak for a period of 10 minutes.
It is then centrifuged again for a period of 2 minutes at
400 G. The sample is then reweighed and the additional
amount of kerosene retained is determined. The total amount
of kerosene retained minus the amount retained after first

centrifuge period is equal to absorption of the aggregate. The surface area and asphalt content are then determined from appropriate charts.

The main difference between the present and proposed CKE Test procedure is that the present method involves only one centrifuging. However, the results obtained combine surface area and absorption. The new modified method involves centrifuging the sample twice, thereby making it possible to obtain the true surface area and true absorption. Therefore, in future specifications, this determination will permit us to limit the absorption and eliminate the undesirable expansive aggregates.

Future Studies

1. Our test results have shown that some test bars fabricated from absorptive aggregates expand as much as 2% longitudinal. The pressures, longitudinal and transversal, that these expansive mixes are capable of exerting are not known. Equipment is now being designed which will measure these forces, not only in the test bars, but also in existing AC pavements.

2. It is further proposed to determine by X-Ray diffraction analyzer and D.T.A. tests if there is an element, or a group of elements, which can be identified with expansive aggregates. If so, we hope to find some method to control their expansive properties.

3. To increase our field-laboratory correlation studies, it is proposed that test bars be fabricated from certain preliminary AC mix designs and some construction control samples, particularly when absorptive aggregates are involved.

4. Set maximum absorption values on aggregates which will be used in construction of AC mixes.

Conclusions

It is concluded from the test data presented that:

1. There is a relationship between the percent absorption of the aggregate as determined by the modified CKE Test and the expansion and contraction of the mix. Generally, the higher the absorption, the greater the expansion.

2. Maximum expansion usually occurs during the wet cycle. However, several figures show maximum expansion occurred during first 24 hours of the dry cycle. The reason for expansion during the dry cycle has previously been discussed.

3. Maximum contraction occurs during the dry cycle.

4. AC test bars generally continue to expand during the test cycle and usually do not return to their original length.

5. Inherent strains are capable of cracking test bars without the aid of external forces.

6. Tests to date show expansion can be reduced by removing expansive clays from the aggregate mix.

7. Tests indicate that an increase in asphalt content usually reduces expansion in the wet cycle.

8. Expansion can be reduced by some mineral fillers, while another filler may encourage expansion.

9. An ideal expansion suppressor would be a filler, natural or manufactured, which would absorb the moisture entering into the AC pavement without increasing in volume.

10. Studies made to date show good correlation between expansion bars and actual pavement conditions.

11. A new test procedure has been presented which will aid the engineer in making a more prudent analysis of the aggregates he will use in the construction of AC pavements.

There are still many questions about the causes and effect of expansion and contraction which have not been answered. We feel, however, when this study is completed, the information gained will aid in better understanding the causes of AC pavement failures. Knowing the causes of certain types of failures, we feel that corrective measures can be taken to prevent these failures.

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APPENDIX A
Procedure for Fabricating Asphalt Concrete Bars
(3" x 3" x 11.25")

1. Place approximately 4000 grams of the asphalt concrete mixture in a 230°F oven for at least two hours.

2. Into a 3" x 3" x 11.25" steel mold preheated to 140°F, place sufficient asphalt concrete mix to fill the mold 1/2 full. (Figure A)

3. Rod the mix 20 blows with a 3/8" diameter bullet-nosed rod.

4. Add sufficient material to fill the mold.

5. Rod second lift 20 blows. (Be sure mix is well rodded around end pins.)

6. Compact specimen for 5 minutes at 15# pressure on the dial of the kneading compactor (125 psi).

7. Continue compaction for an additional 5 minutes at a pressure of 31# on the dial of the kneading compactor (250 psi).

8. Place steel plate (2-7/8" x 1/4" x 11") on specimen and compact for two minutes at the 31# pressure for leveling off load.

9. Strip mold from specimen and place compacted specimen on sheet of plywood.

10. Secure steel end pins to test specimen with epoxy resin.

11. Leave specimen in 100°F oven for approximately 63 hours.

12. At the start of the test, record length of AC bar and place bar in moist room. Daily measurements will be made and recorded.

13. After 7 days in the moist room, place the AC bars in the 100°F oven. Measurements will be made every two hours for the first day.

14. After the first 8 hours in the 100°F oven, measurements will be made once a day for the remainder of the 7 day period, at which time the specimen will be placed again in the moist room and the second cycle will begin. This will continue for three cycles; however, in some special cases, the tests will continue for six cycles. (One cycle equals seven days in the moist room and seven days in 100°F oven.)
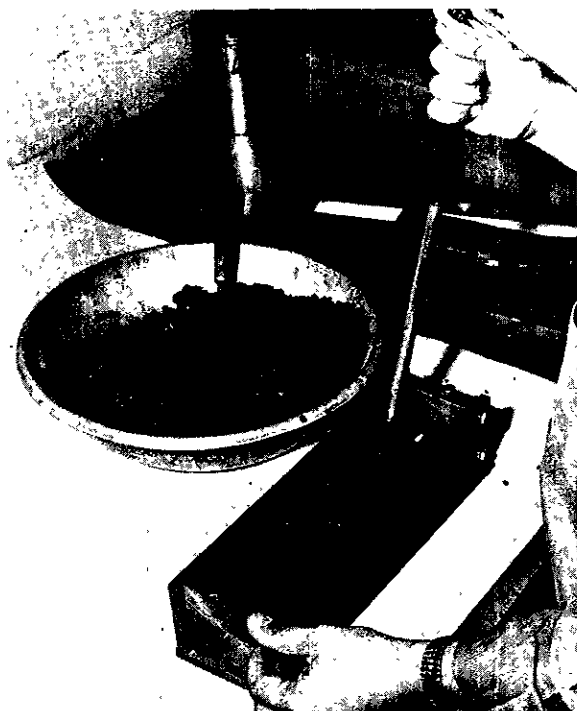
Fig. A - AC mix being rodded with 3/8" bullet nose rod.
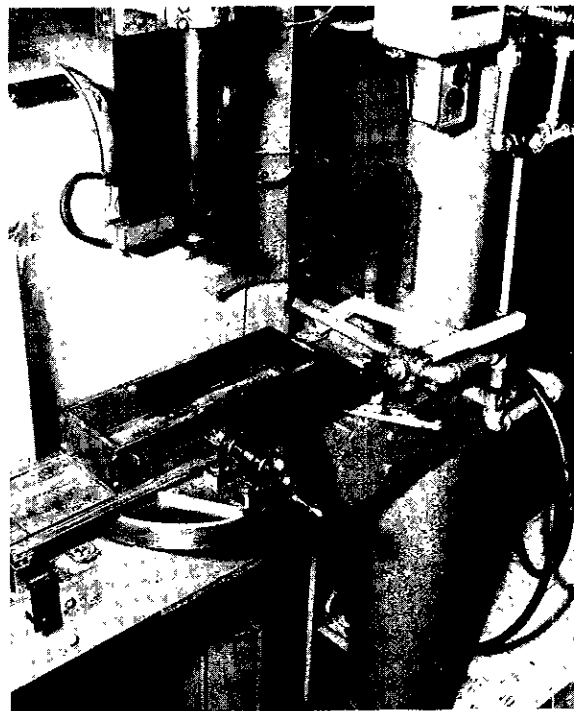
Fig. B - Mold carriage which holds steel mold during compaction.
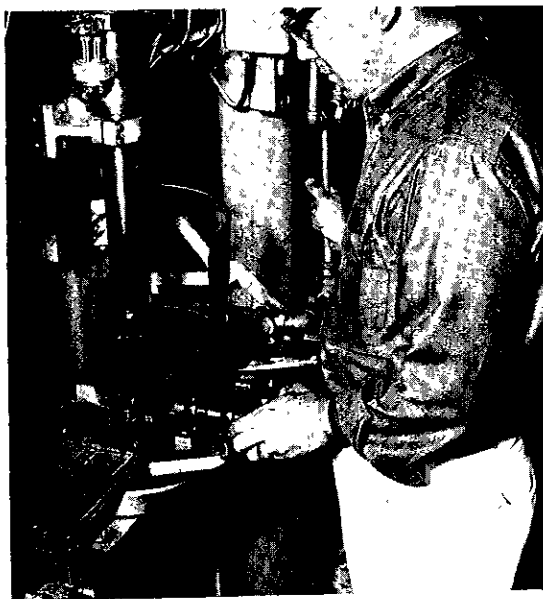
Fig. C - AC mix ready to be compacted. Note rectangular compacting foot (2" x 3")
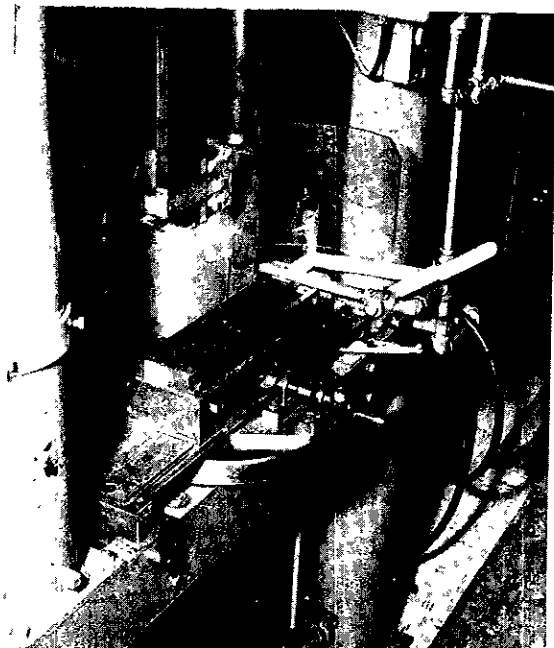
Fig. D - AC bar being fabricated.
Crank is turned 1/4
revolution after each
stroke of compactor
foot.
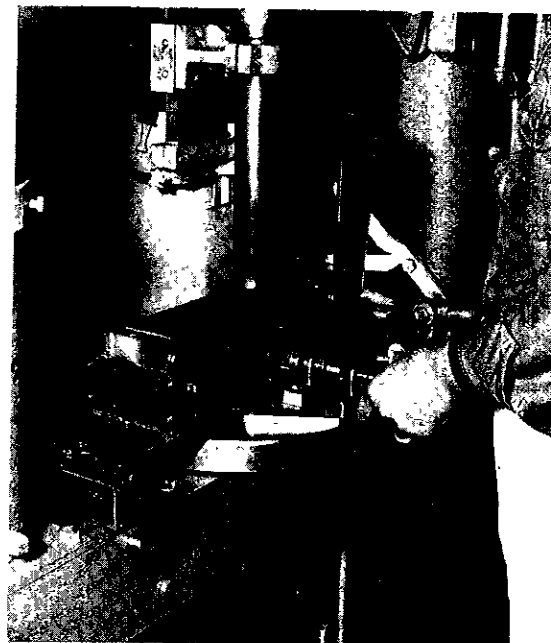
Fig. E - AC bar receiving leveling
off load.
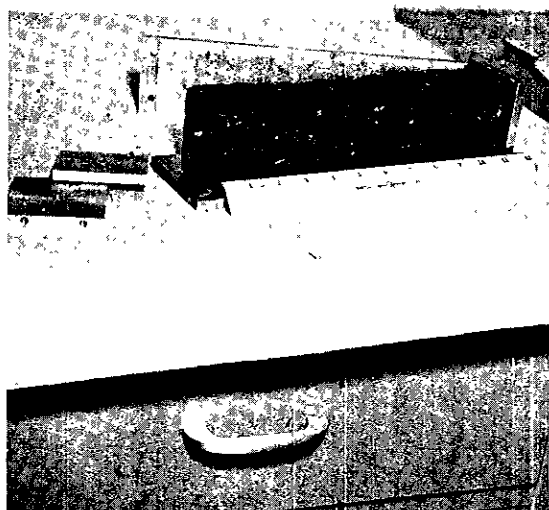
Fig. F - Metal mold being stripped
from AC bar. Note steel
pins used for measurement.

Fig. G - Finished AC bar showing
steel pins secured into
bar with epoxy.

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TABLE 1

Agg. Class. (X-Ray&DTA)	% Absorp. (Mod.CKE)	% Asph 85-100	*Stabs Comp. Press. 350 psi	Comp. Press. 500 psi	**Coh. Comp. Press. 350 psi	Comp. Press. 500 psi	Sp. Gr. Comp. Press. 350psi	Comp. Press. 500 psi
57-854 (Non-Absorptive) Quartsitic Meta Sand Stone Diabase (River Sand & Gravel)	0.0	5.3	32	42	420	683	2.35	2.37
57-1236 (Absorptive) Volcanic Dacite & Rhyolite Felospar,Quartz Calcite & Mica	1.0	6.3	34	38	227	312	2.07	2.09

*Stabilometer Value
**Cohesiometer Value

TABLE 2

	Agg. Class. (X-Ray&DTA)	% Absorb. (Mod CKE)	% Asph 85-100	Stab Value	Coh.	Sp. Gr.
62-1863	Weathered Andesite	1.2	6.9	37	255	2.11
62-1908	Weathered Andesite;some Tuff; minor Quartz	0.8	6.5	39	279	2.13

TABLE 3

Samples	Agg. Class. (X-Ray&DTA)	% Absorb. (Mod CKE)	% Asph 85-100	Stab Value	Coh.	Sp. Gr.
From exist. pav't.	Volcanic-Olivine Basalt&Andesite weathered, & altered	--	6.3	37	247	1.98
Fabri-cated in lab.	Feldspar Montmorillonite	1.9	6.3	39	170	2.03

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<div align="center">TABLE 4</div>

	Aggregate Classification	% Absorp. (Mod. C.K.E.)	% 85-100 Asph.	Stab. Value	Coh.	Sp. Gr.	Lineal Ft. Cracks Per 100 Ft.
Control	Granite, Andesite & Rhyolite	0.4	5.0	36	164	2.37	30
Filler	A		5.3	37	400	2.36	132
Filler	B		4.8	38	315	2.38	22
Filler	C		4.5	37	220	2.37	42

Fig. 1 - Epoxy coated specimen exposed on roof at end
of 6 months. Both specimens fabricated from
absorptive aggregates.
Left - Specimen compacted at 500 psi.
Right - Specimen compacted at 350 psi.
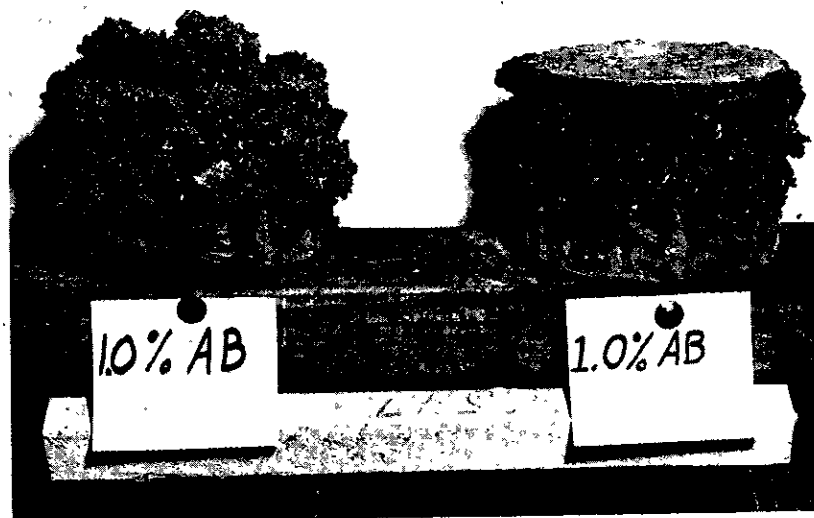
Fig. 2 - Same specimen as in Fig. 1 after 1 year.
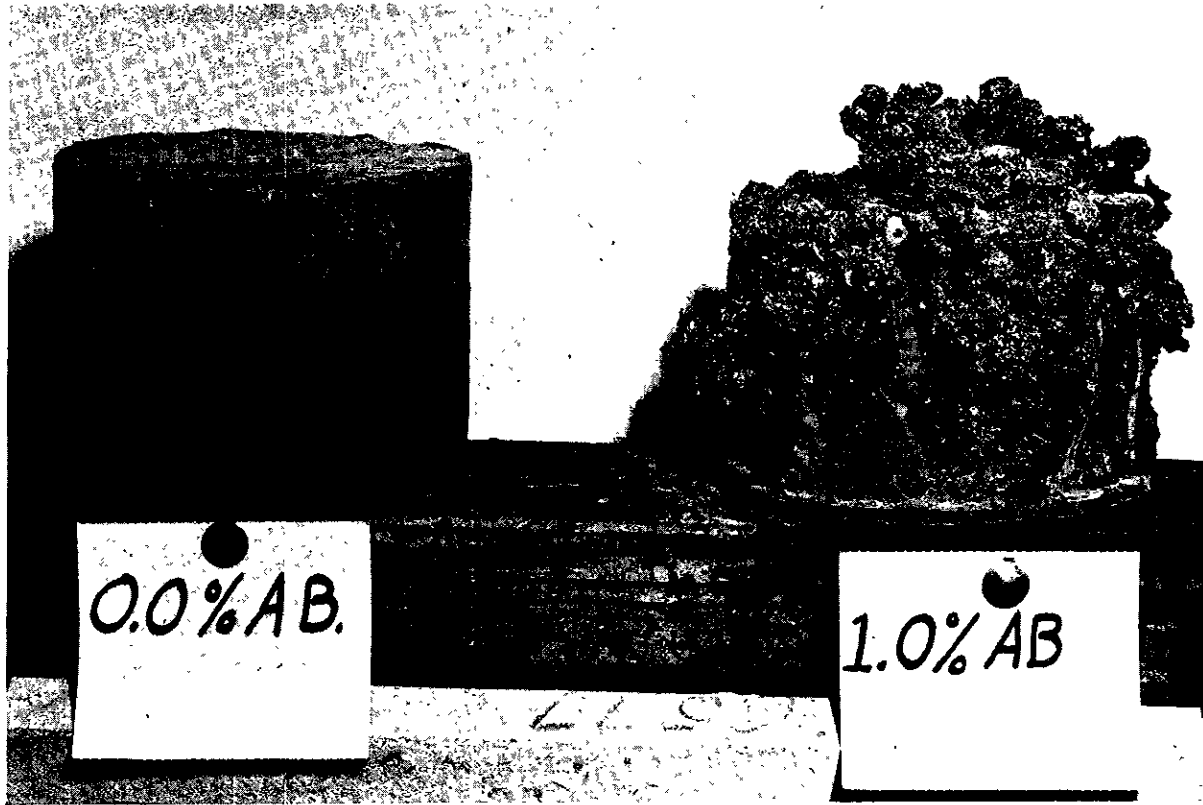
Fig. 3 - Epoxy coated specimen after 1 year.
    Left - Nonabsorptive aggregate.
    Right - Absorptive aggregate.
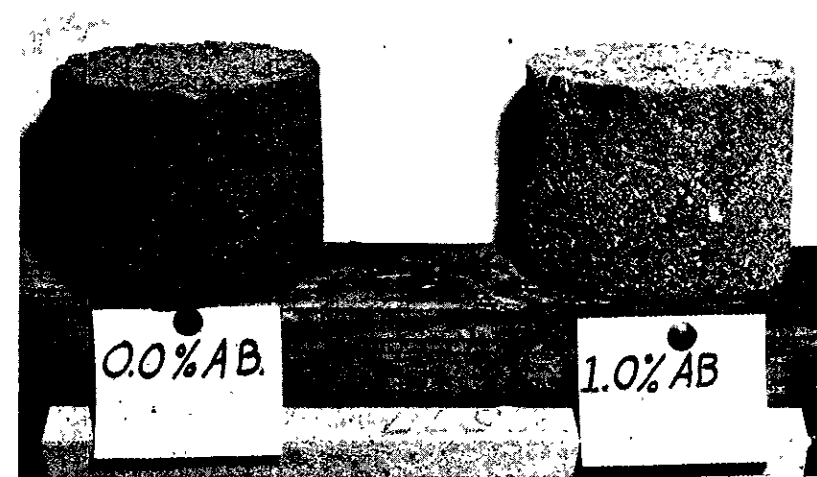
Fig. 4 - Noncapsulated specimen exposed on roof after
          6 months.
          Left - Nonabsorptive aggregate.
          Right - Absorptive aggregate.
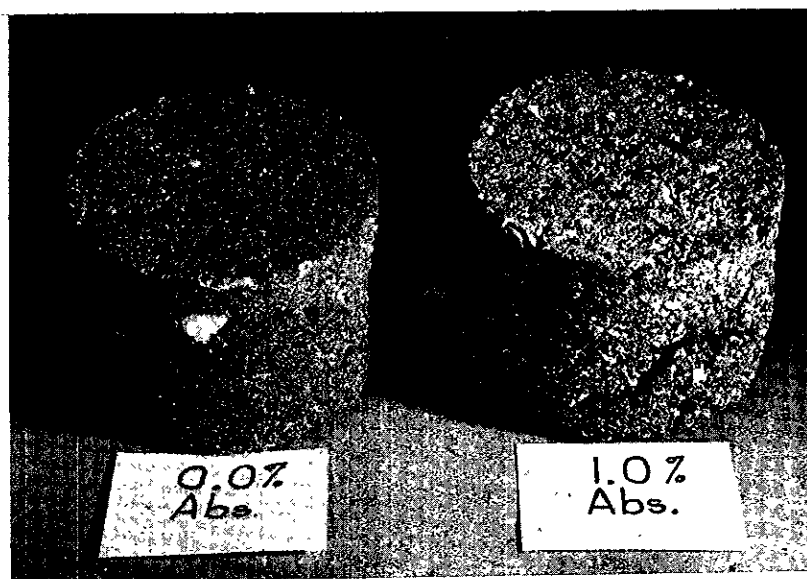
Fig. 5 - Same briquette as shown in Fig. 4. After 6 years.
          The briquette made from absorptive aggregates (1.0%)
          had an increase in volume of 18.8%. No increase in
          volume was noticed in the briquette fabricated from
          the nonabsorptive (0.0%) aggregate.
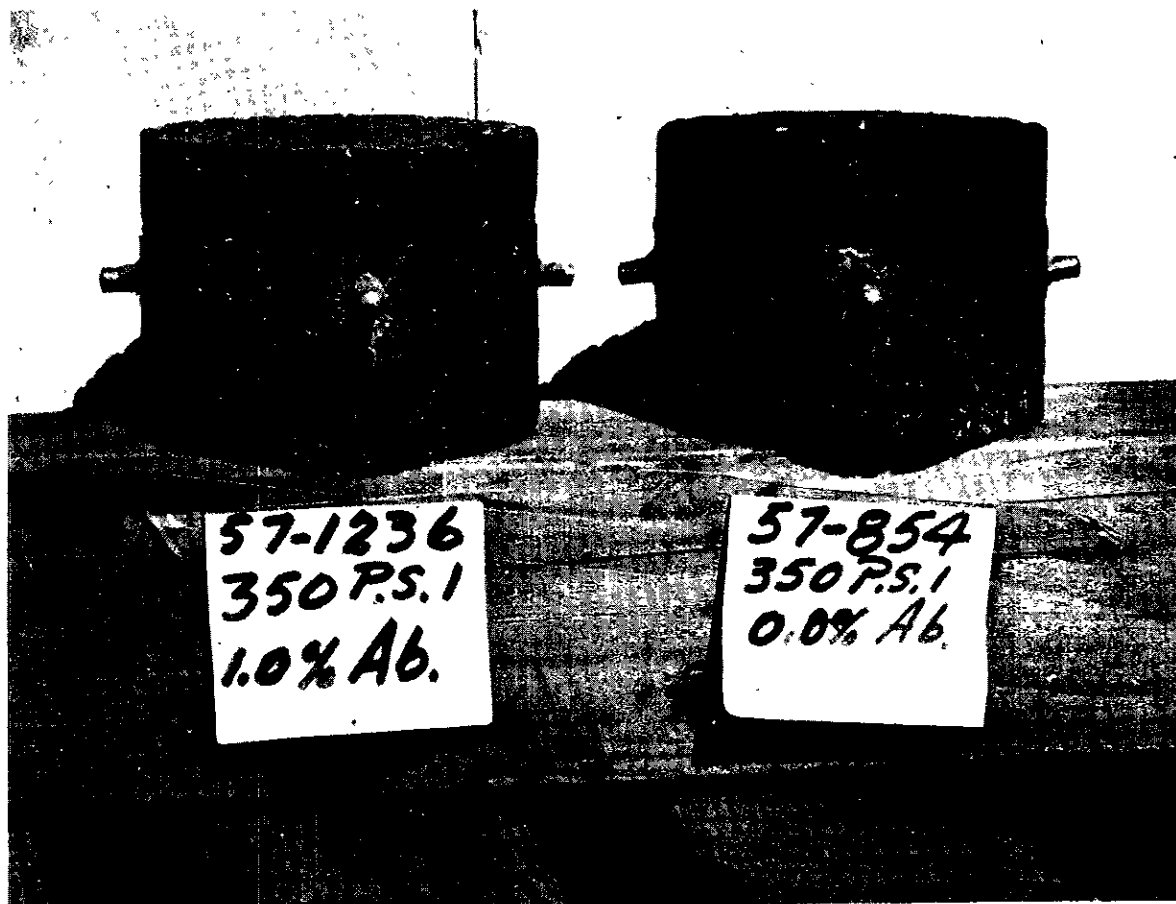
Fig. 6 - Stainless steel pins cemented to sides of
specimen to measure volume changes.
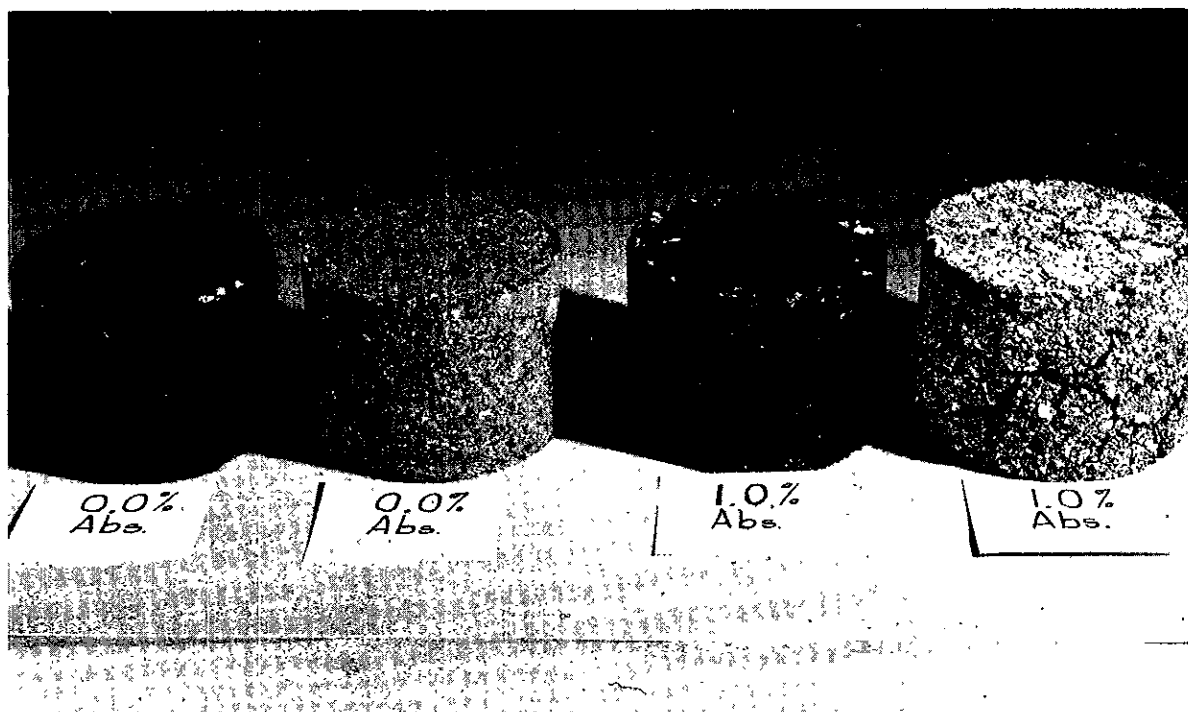
Fig. 7 - Absorptive and nonabsorptive AC briquettes.
Dark colored specimen stored in cabinet for 6 years.
Light colored specimen exposed on roof for 6 years.
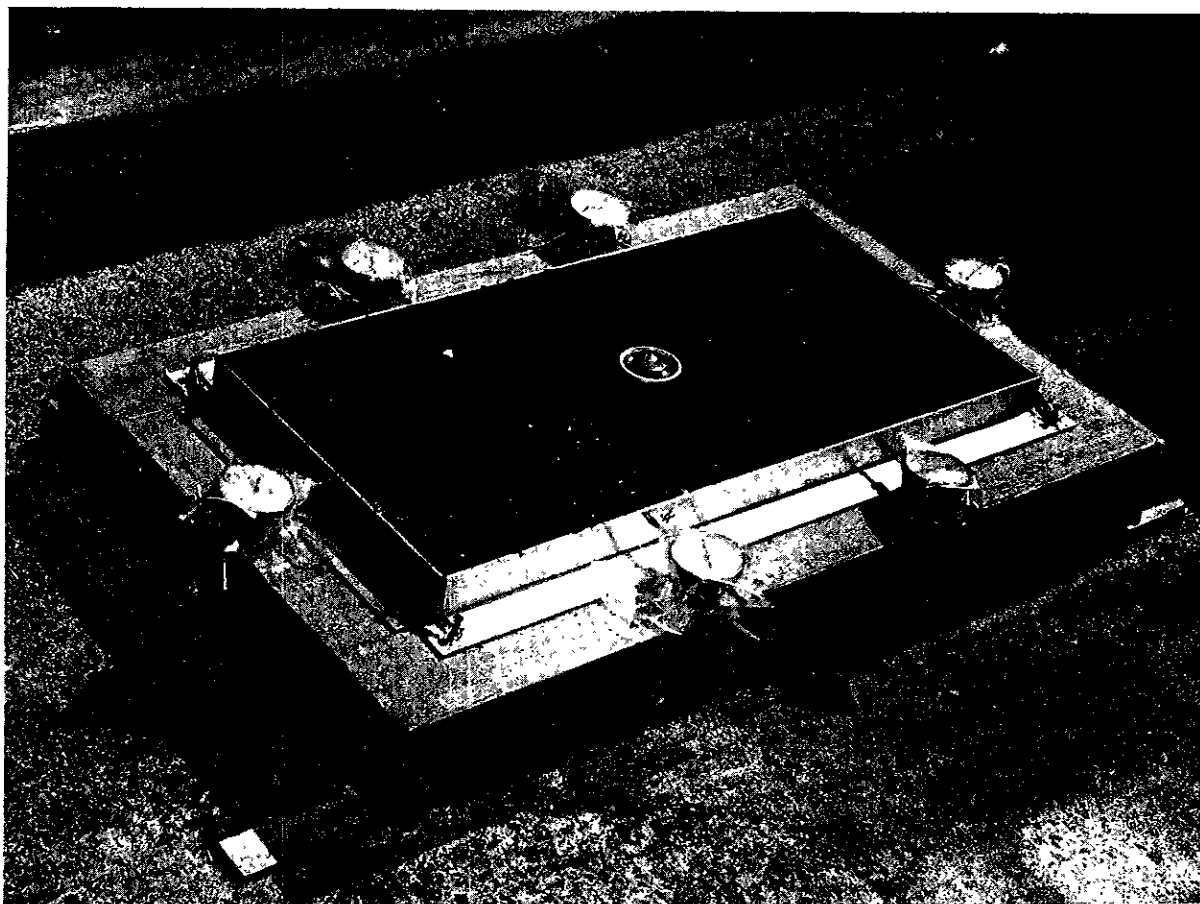
Fig. 8 - Slab specimen 1' x 2' x 3". Note springs holding
aluminum sides surrounding surface course.

TEST NO. 57-1236

FIGURE 9

TEST NO. 57-1236

FIGURE 10

Chart labels:
- Vertical axis (left): EXPANSION & CONTRACTION (IN.) — .160, .120, .080, .040, .000
- BOX BROKE
- Absorption = 1.0 %
- TIME axis values: 1530, 1330, 1130, 0930, 0730 (repeated per group)
- DATE axis: 9-18, 8-25, 8-15, 7-27, 7-14, 6-30, 6-19
- TIME
- DATE
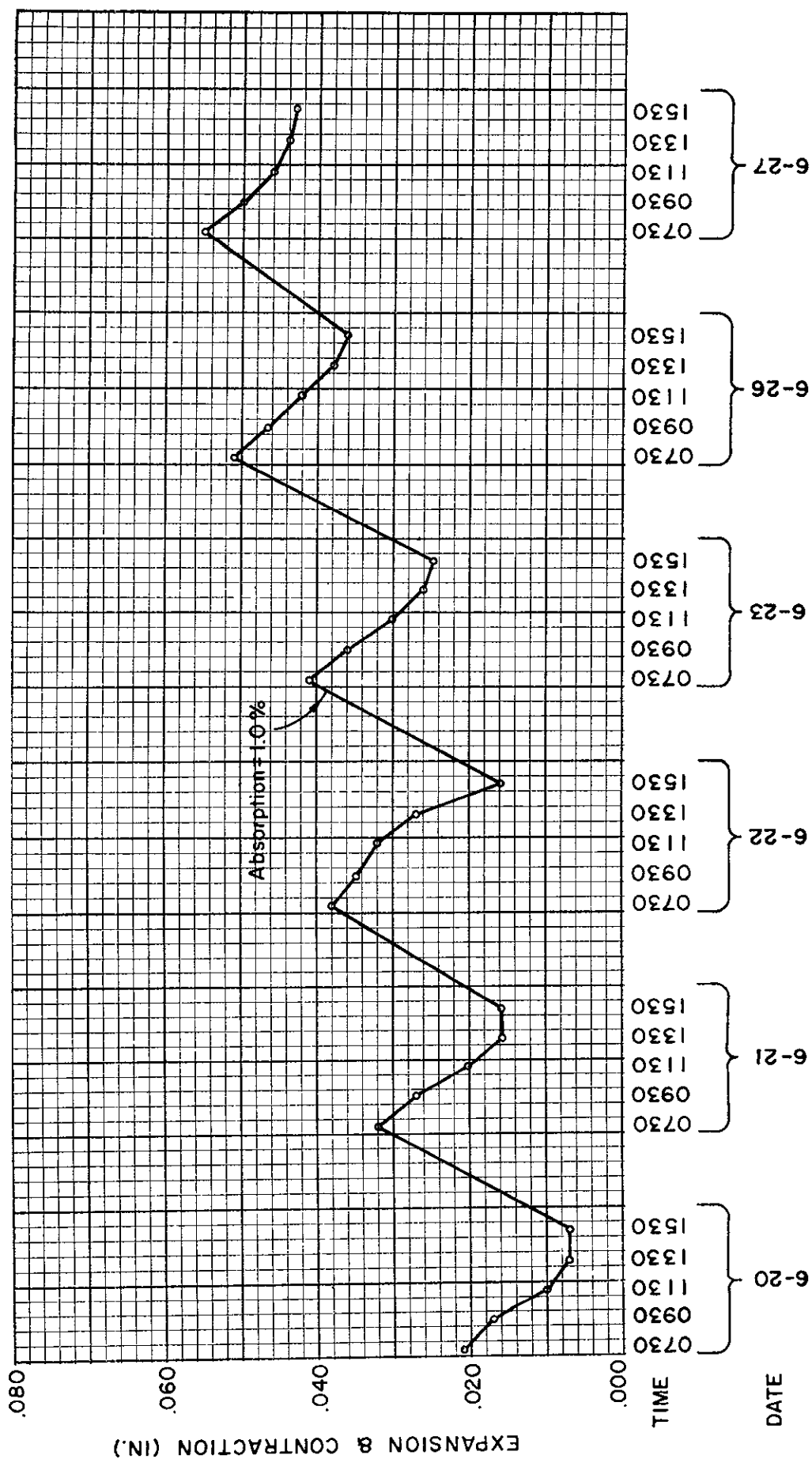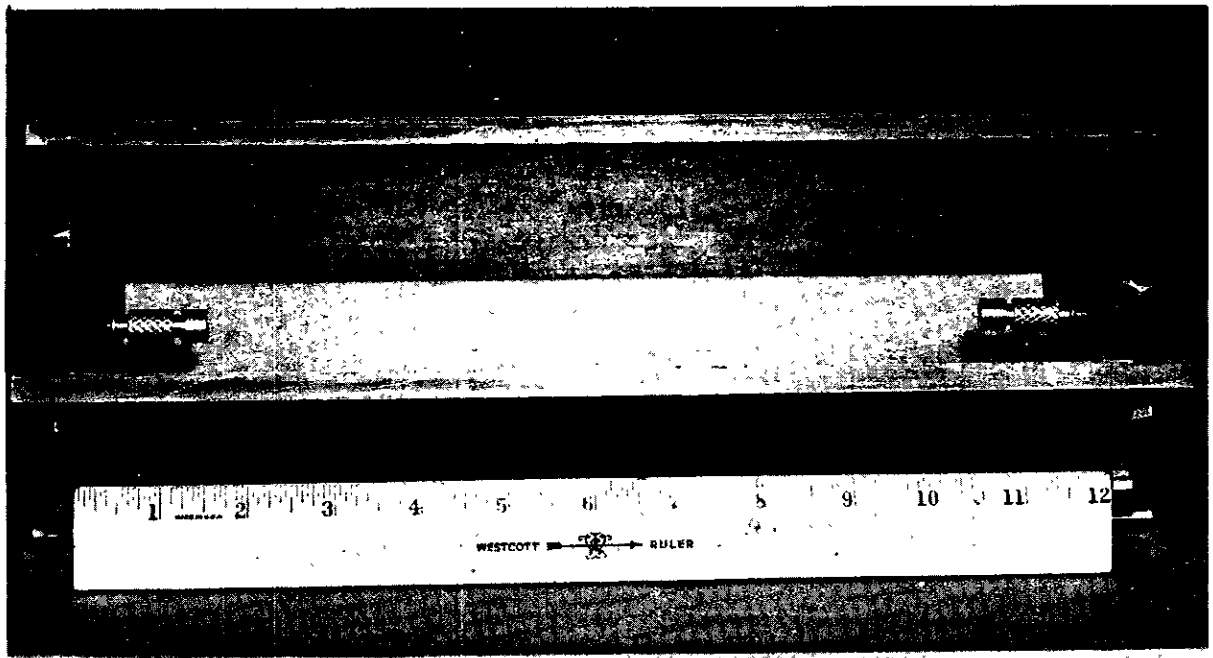
Fig. 11 - Steel mold 3" x 3" x 11.25" used for fabricating
bars. Note steel pins in end of plates for
measuring AC bars.
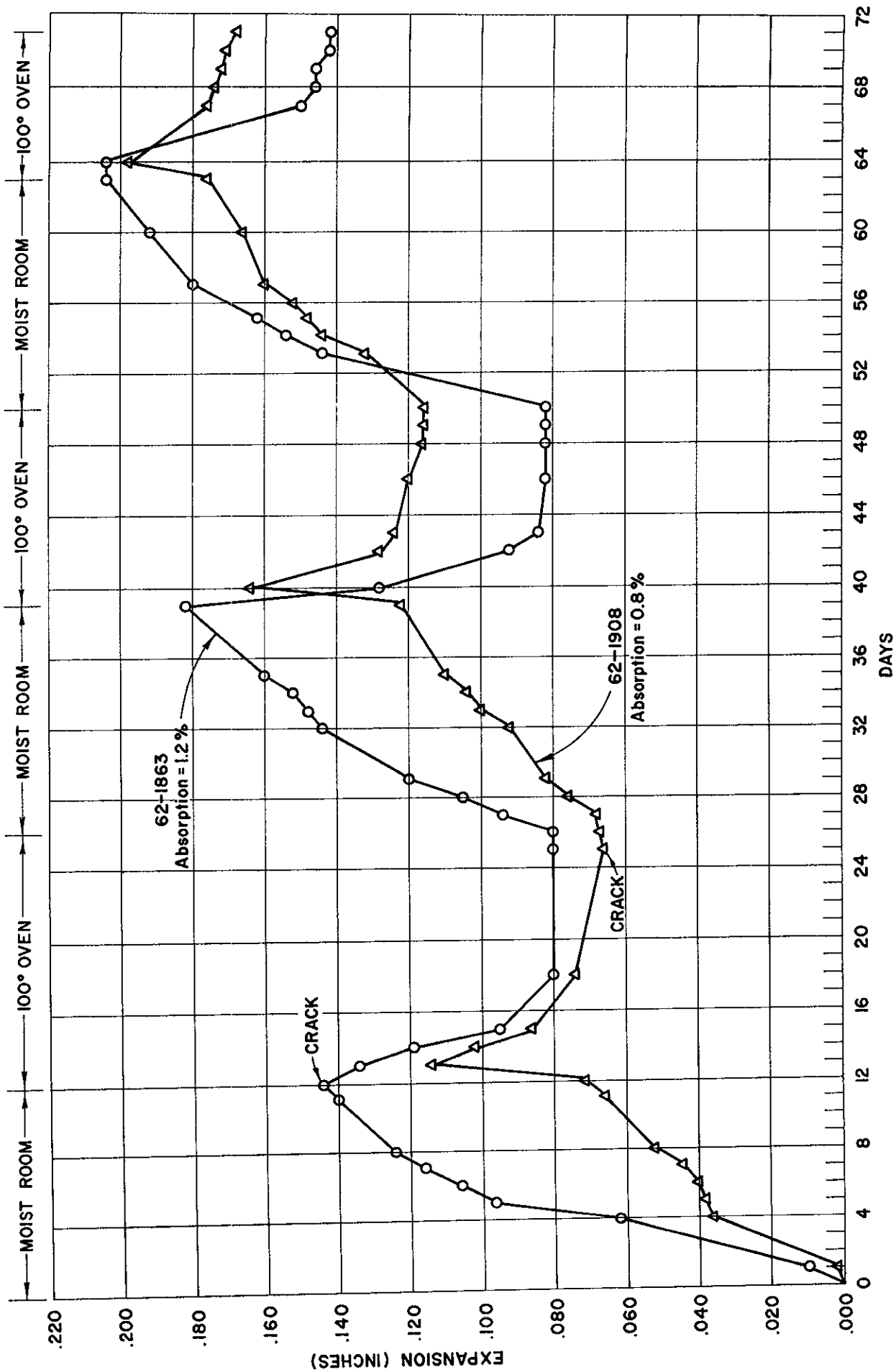
TEST NO'S. 62-1863 & 62-1908

FIGURE 12
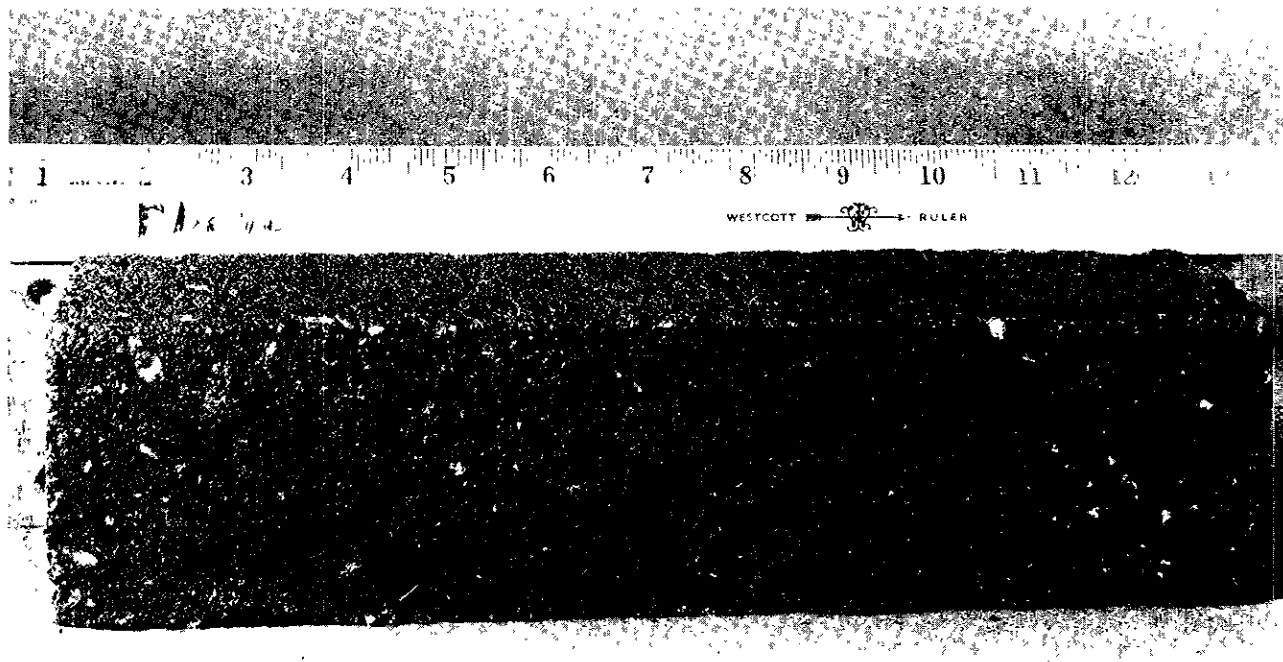
Fig. 13 - Test bar 62-1908.
Transverse cracks appeared after the first cycle.

Fig. 14 - Test bar 62-1863.
At end of third cycle, test bar was completely
block-cracked. A 1/2" section was sawed from
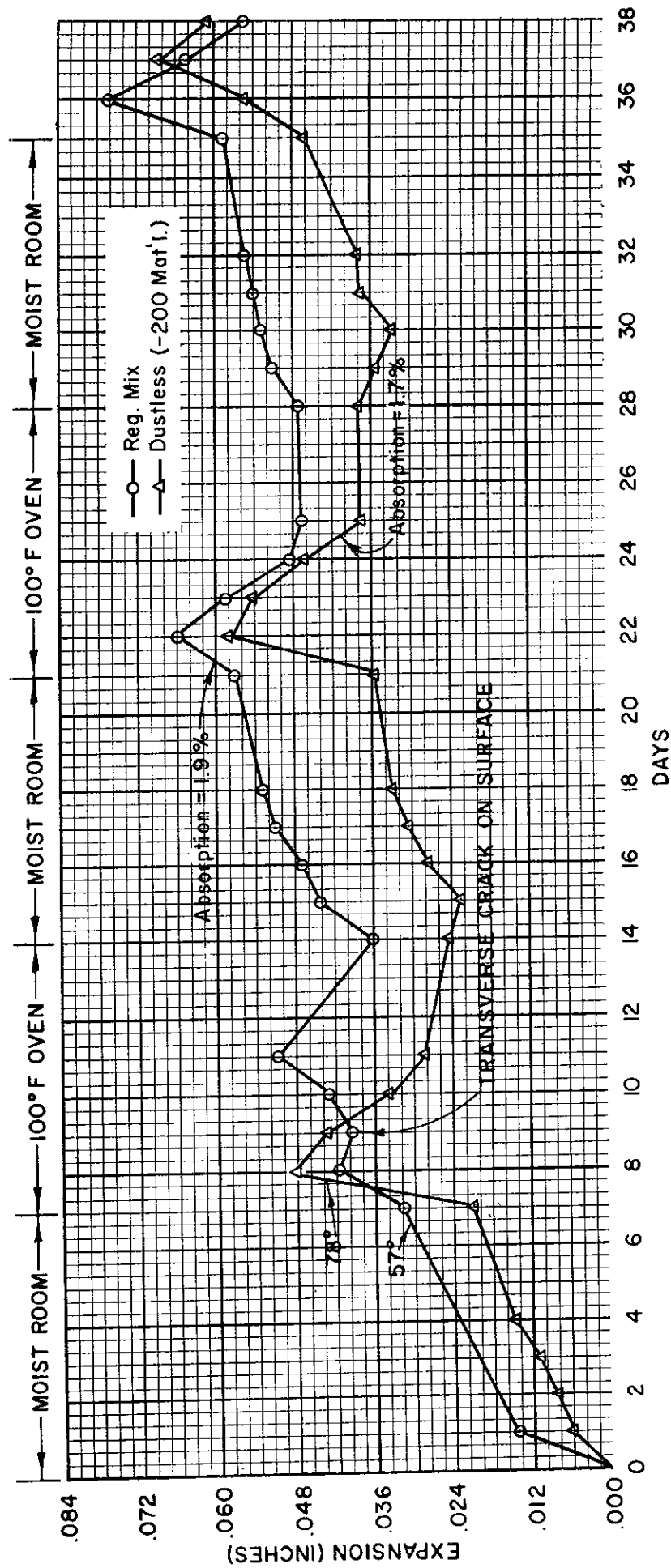center of test bar for micro-viscosity test.

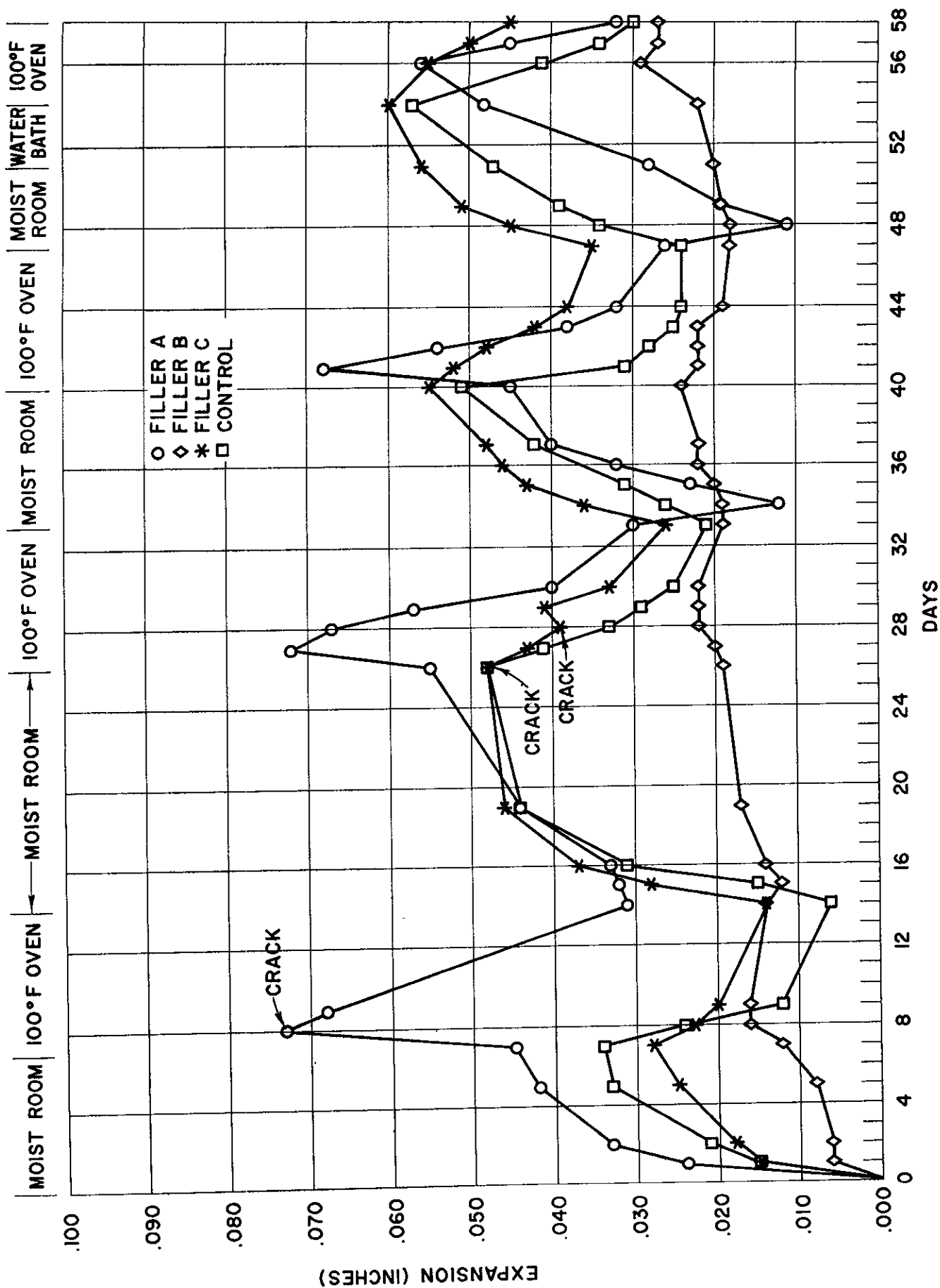Fig. 15 - Transverse cracks ranging from 3/4" to 1-1/2" in width.
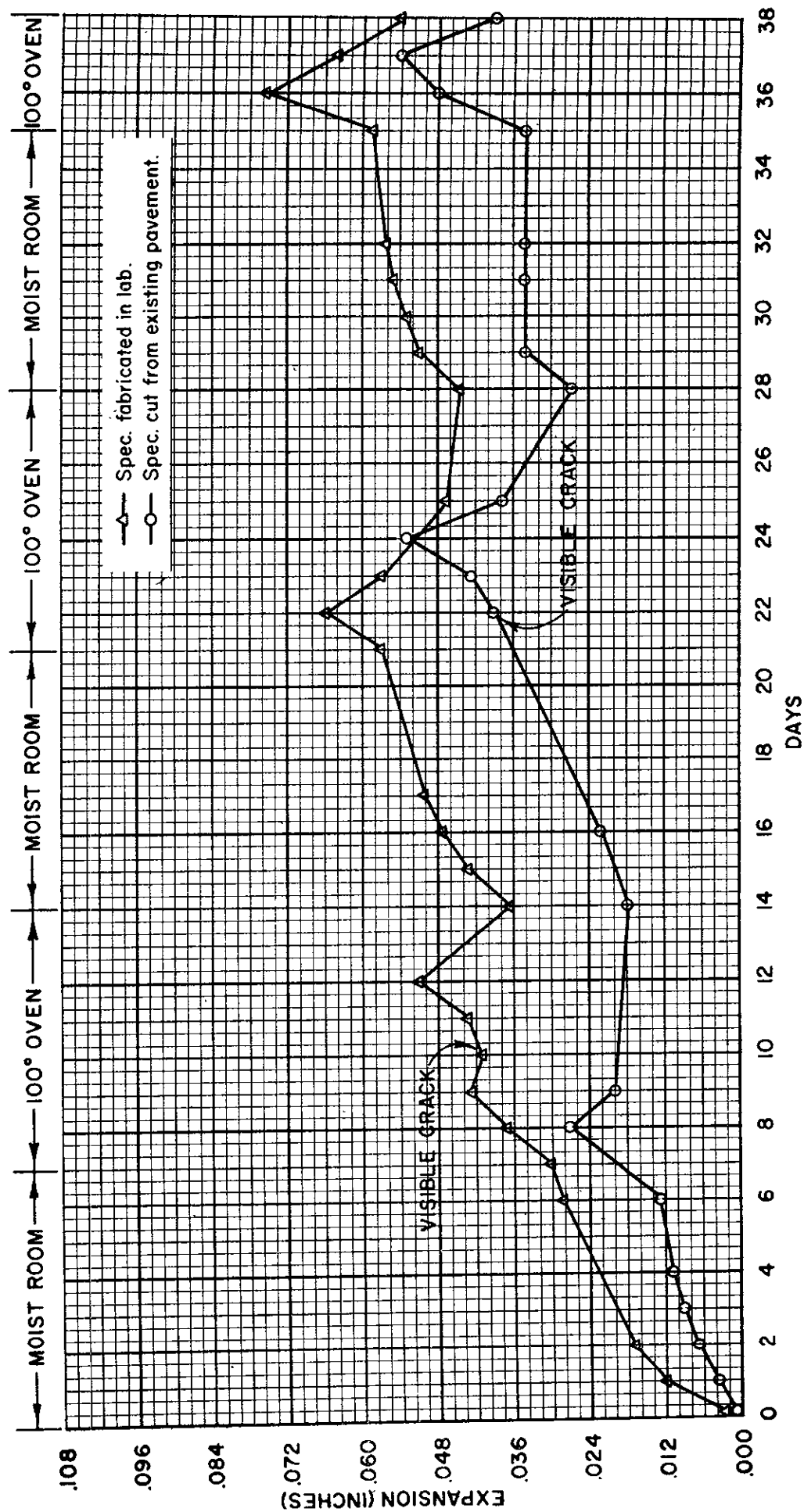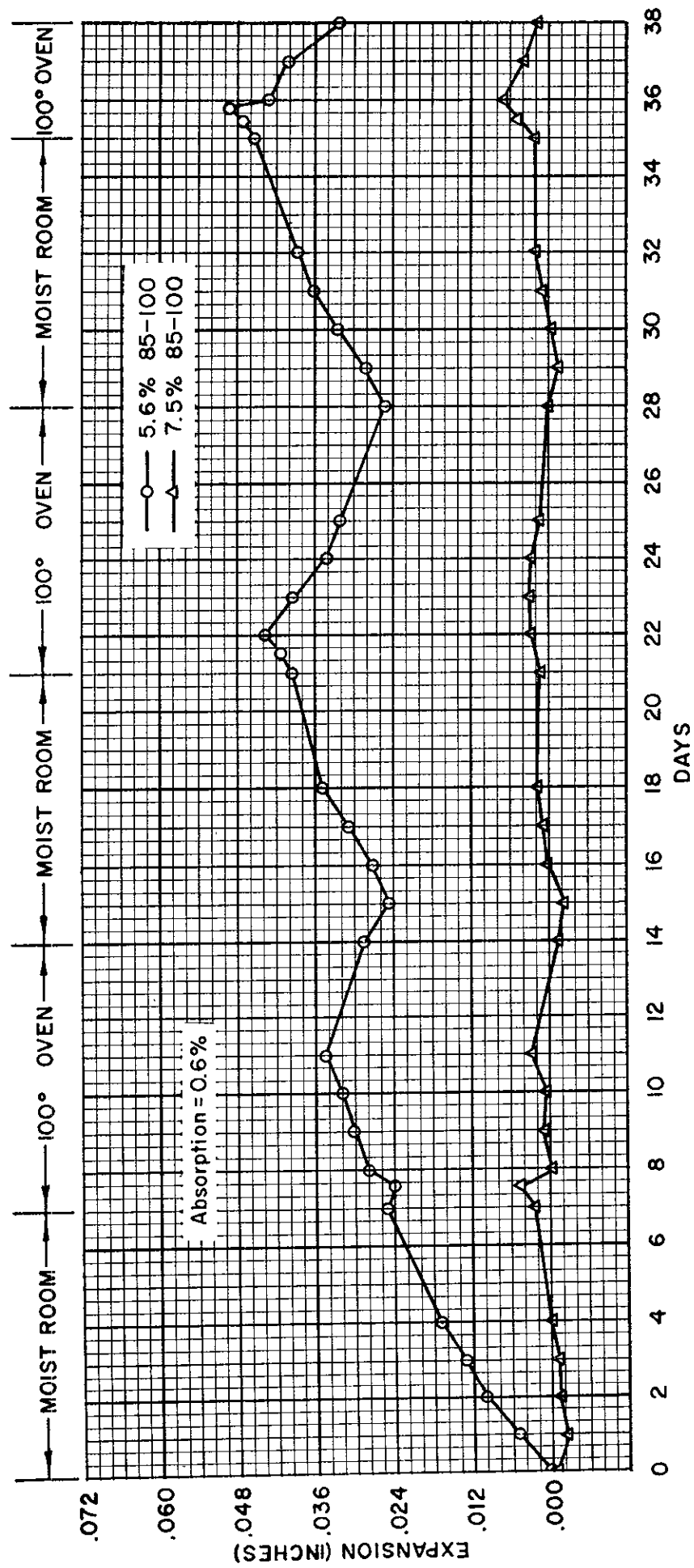
TEST NO. 62-5748

FIGURE 16
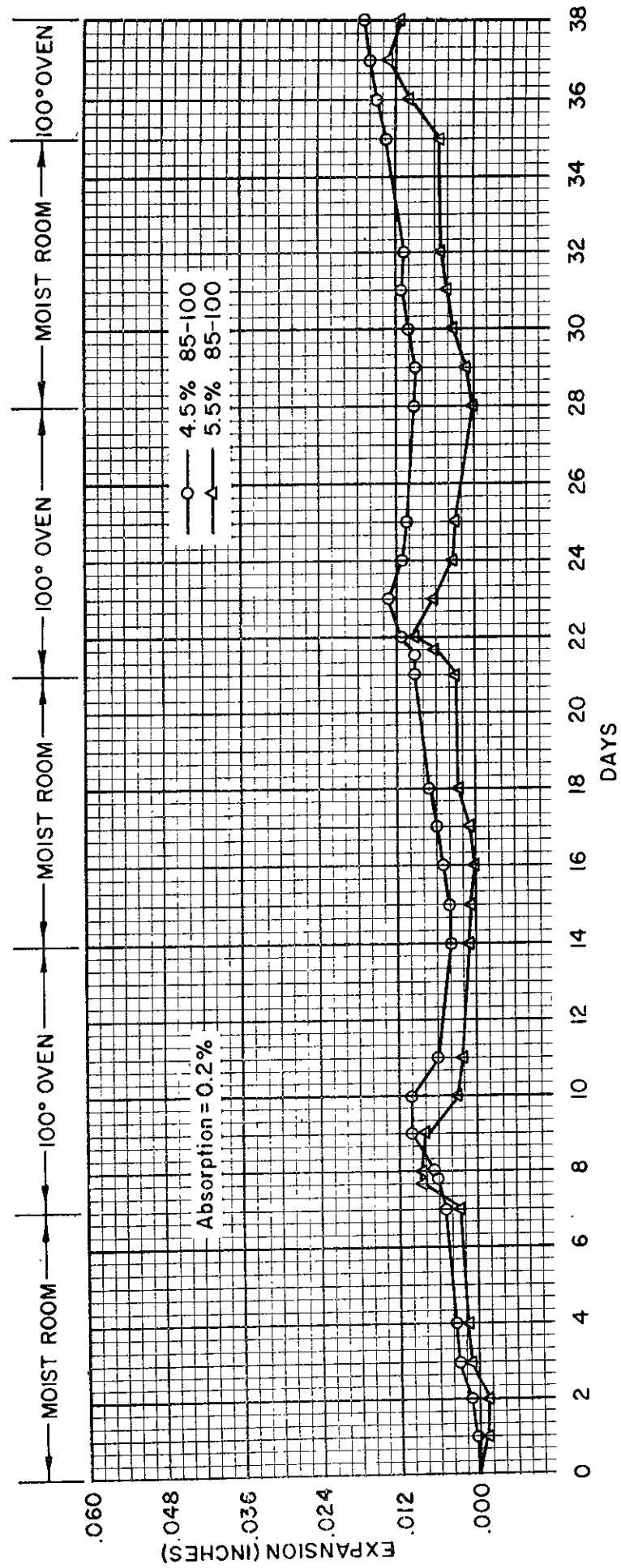
TEST NO. 62-5748

FIGURE 17

EFFECT OF VARIOUS FILLERS

FIGURE 18

TEST NO. 64-1769

FIGURE 19

TEST NO. 64-1539

FIGURE 20